Center for Materials Research (CMR)

Center for Photonic Materials Research (NSF)

Center for Organic Photonic Materials Research (DOD)

Center for Research and Education in Advanced Materials (NASA)

Norfolk State University (NSU)

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Associate Professor of Chemistry and Materials Science

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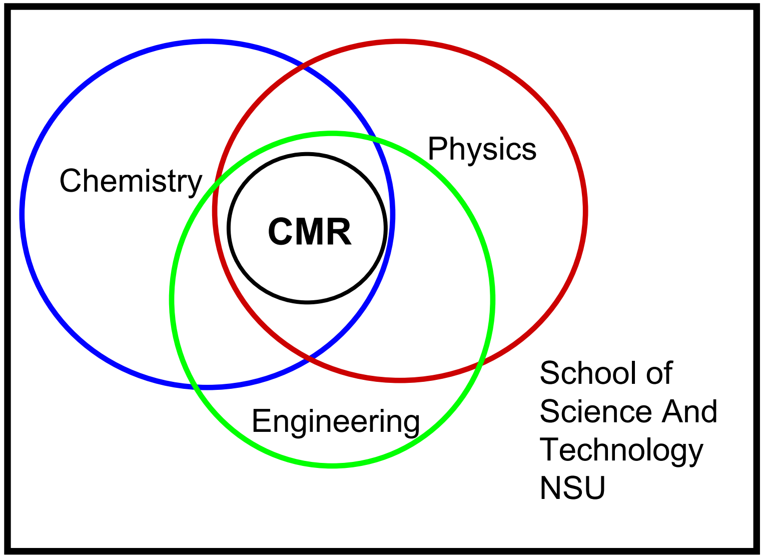
"NSU is primarily a teaching university with pockets of outstanding research"

M.V. McDemmond, NSU President



- **CMR was established in 1992 with initial grant support from NASA, and subsequently supported by DOE, DOD, NSF, OE, FAA, NASA, Dozoretz Fundation, etc.**
- **Currently there are 9 faculty members from 3 departments within the School of Science and Technology, 8 research associates, 4 staff members and over 50 students.**

‘CMR’ Capabilities

- Synthetic/processing capabilities
  - Organic and polymer synthesis and characerizations
  - Single crystal growth
  - Nano particle synthesis and characterizations
  - Thin film processing and characterizations
  - Glass preparations
- Characterization capabilities
  - Optical spectroscopy
  - Magnetic spectroscopy
  - Electrical Measurements
  - Electron Microscopy (SEM, AFM)
  - Surface analysis
  - Thermal Analysis
  - X-ray diffraction
  - Molecular/particle size analysis

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Research Objectives

- Development of supra-molecular and nano structured polymers (plastics) for inexpensive, lightweight, flexible and high efficiency solar energy conversions.
- Development of novel nonlinear optical (both inorganic and polymeric) and laser materials (crystal and radom lasers) for future photonic device applications.
- Processing, fabrication, and characterization of organic and inorganic nano-layered thin films via spin coating, MVD, OMBE, PLD, etc.
- Study of electron-nuclear spin dynamics in high-spin systems for spintronic and photonic applications.

Educational Objectives

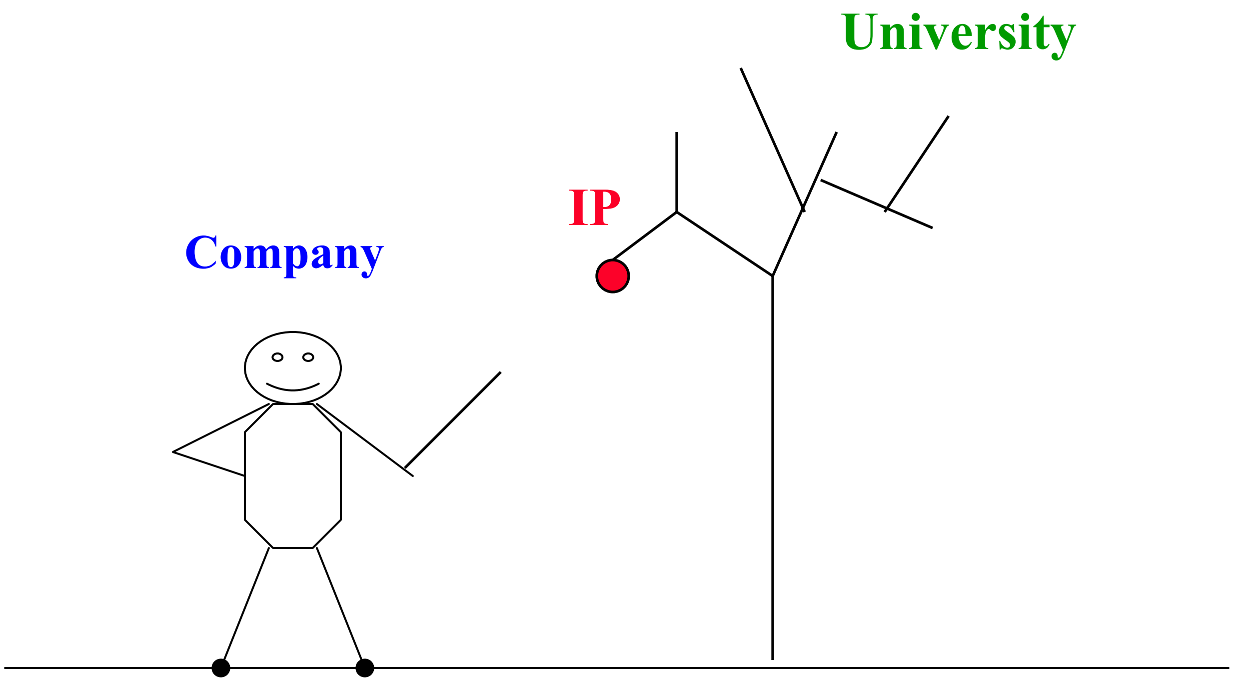
- **Interdisciplinary program: we admit and support students majoring in physics, chemistry and engineering who are interested in obtaining advanced degrees in materials science, particularly in advanced photonic, electronic, spintronic and nano materials and technology.**

- **We train students with basic knowledge and skills in chemistry and solid state physics relevant to materials science and technology, these include materials synthesis, processing, characterizations, spectroscopy, fabrications, etc.**

Collaboration Tips

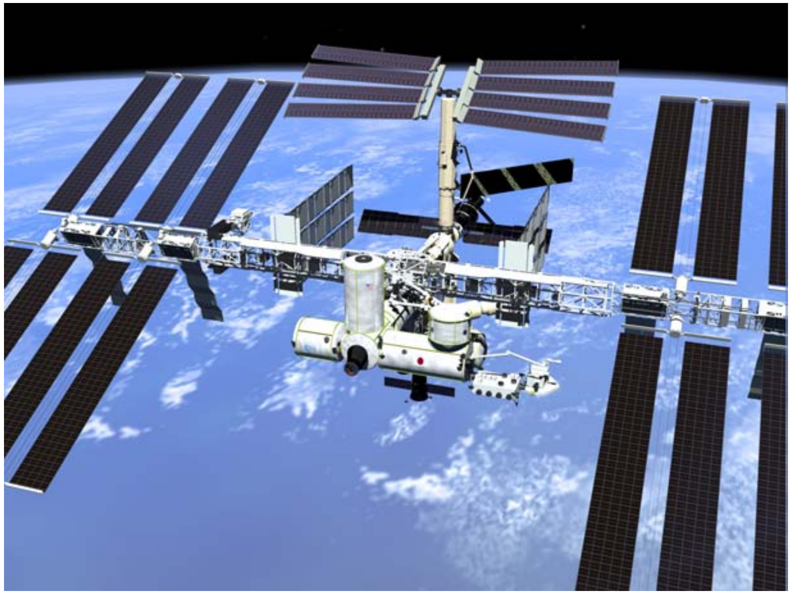
- Research
- Education
- Publications
- IP and Cost Sharing

Partnership of University/Company



Current Collaborators

- NASA Langley Research Center, NASA Glenn Research Center
- Thomas Jefferson National Laboratory
- Hampton University, ODU, UVA, VTech, College W&M, Purdue University
- CREOL, University of Central Florida
- University of Alabama in Huntsville
- University of Washington
- University of Rochester
- Alabama A&M University
- Hamburg University (Germany)
- Institute for Organic Solar Cells (Austria)
- Institute of Chemical Physics (Russia)
- Institute of Chemistry (China)
- Institute of Physics (Poland)
- Center for Photovoltaic Engineering (Australia)
- IBM Almaden Research Center
- NEC Research Institute, etc.



Future Directions and Plans

- **Research**: focus on photonic, electronic, spintronic materials, devices, and nanotechnology.
- **Education**: development of a Ph.D. program in advanced materials science and engineering
- **Facility and space**: expansion into the RISE I Center
- **Funding**: identify new funding opportunities through teaming with mainstream research universities, industry, and other private entities.

Optimization of Self-Assembled Macromolecules (SAM) for SUN Light Harvesting (Solar Energy Conversion)

SAM SUN, Ph.D.

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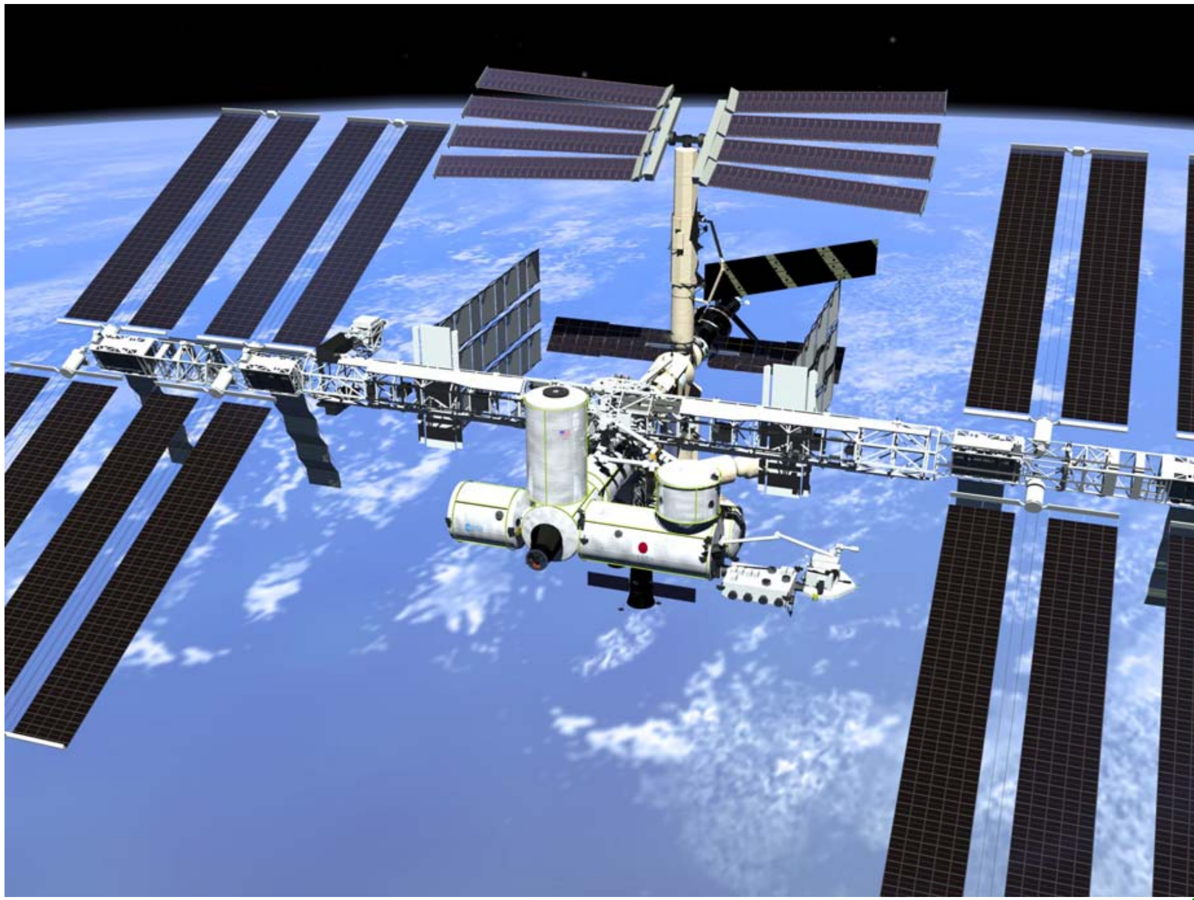
Research Objectives

Investigate and develop supra-molecular self-assembled macromolecules (SAM) for efficient Sun light harvesting (such as solar cell) applications

‘Plastic’ solar cells:

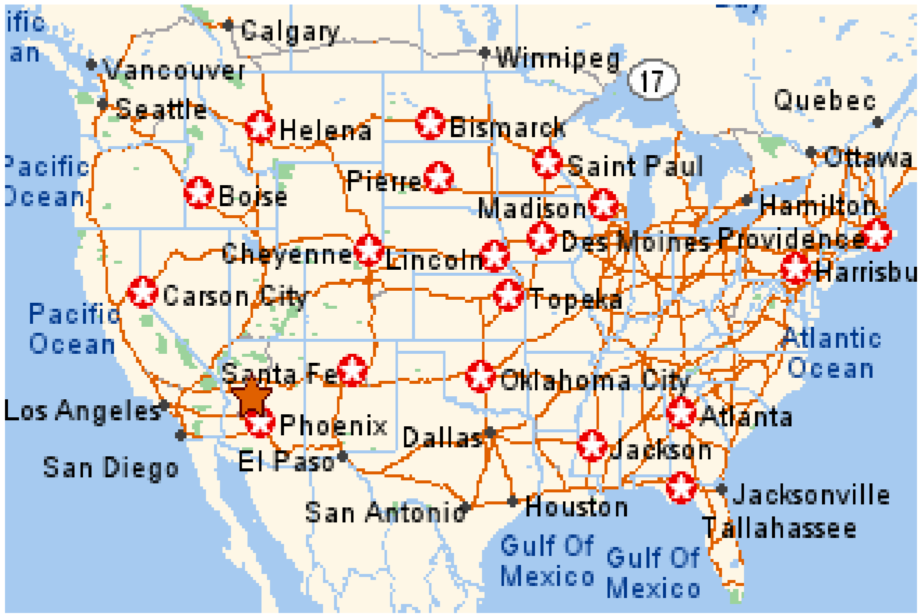
- Light weight
- Flexible shape
- Cost effective
- High efficiency*

Lightweight & Flexible



Lightweight & Flexible

Renewal & Clean Energy II



Electricity needs in United States

≈ 10% Efficiency Solar Cell with a size of 70 x 70 miles

in a SW states (California, Arizona, New Mexico, etc.)

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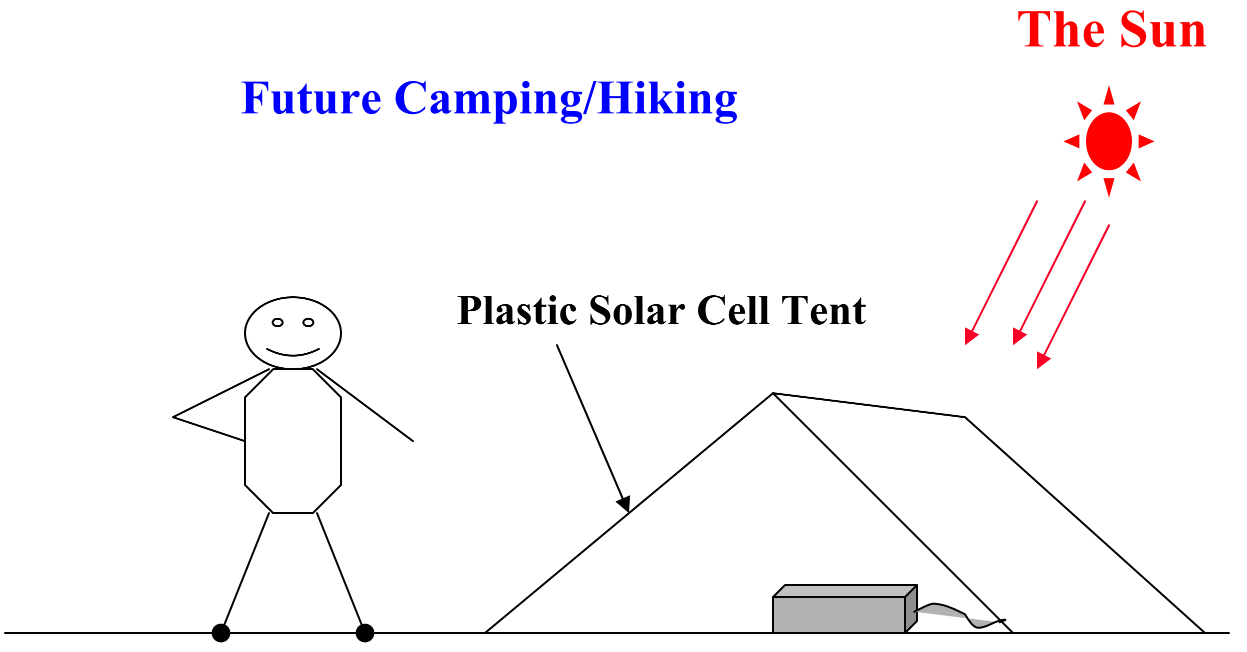
Low Cost Solar Cells are Badly Needed at Remote Sites

Plastic Solar Cells for Campers/Hikers



Renewal and Clean Energy I

Limited, $

Fossil Fuels
(Oil, gas, coal)

Burning (O_2) →

Greenhouse Effect

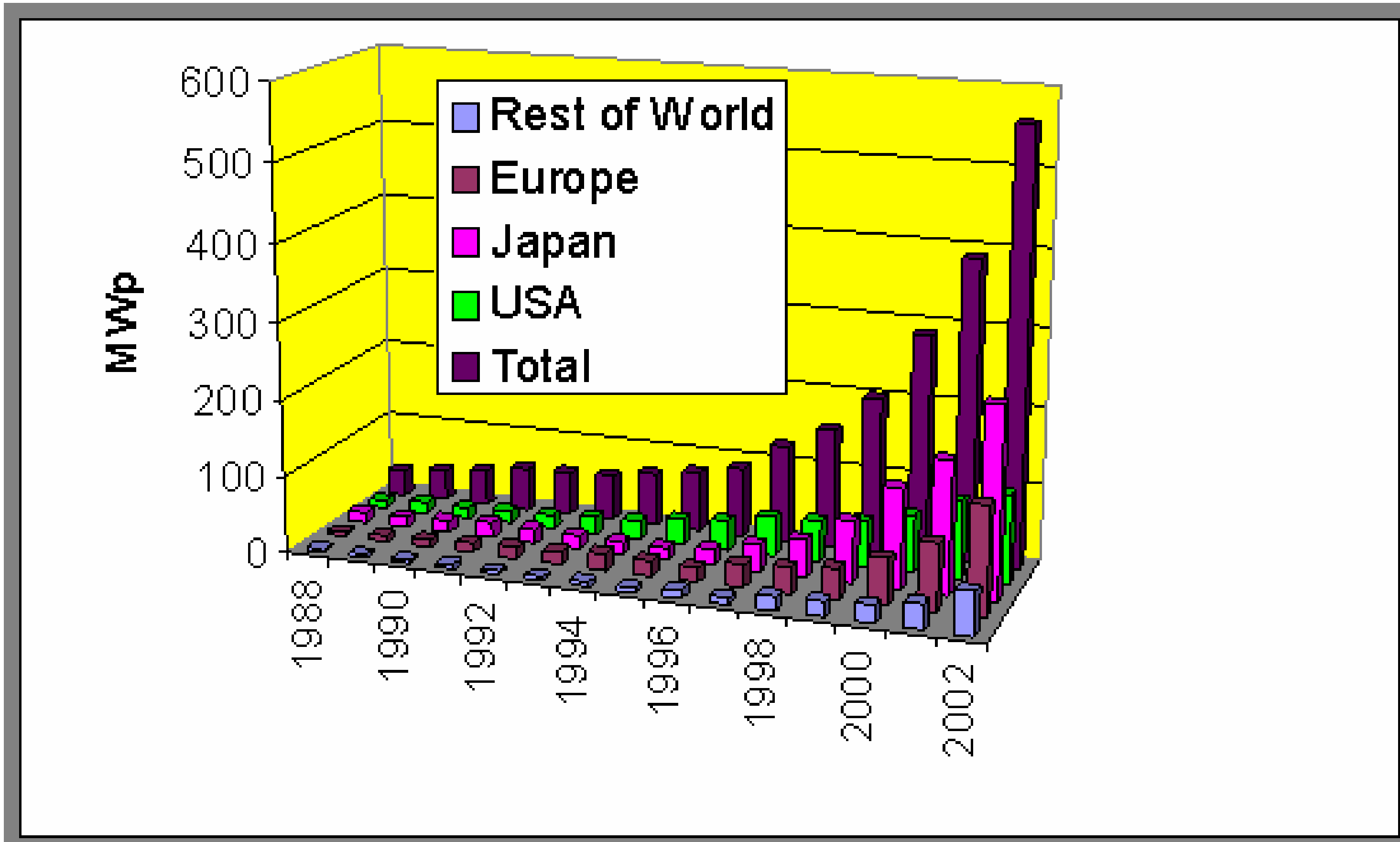
Energy + $\mathbf{CO_2}$ + $\mathbf{H_2O}$ + $\mathbf{N_xO_y}$ + $\mathbf{SO_Z}$

Smog, Acid Rains

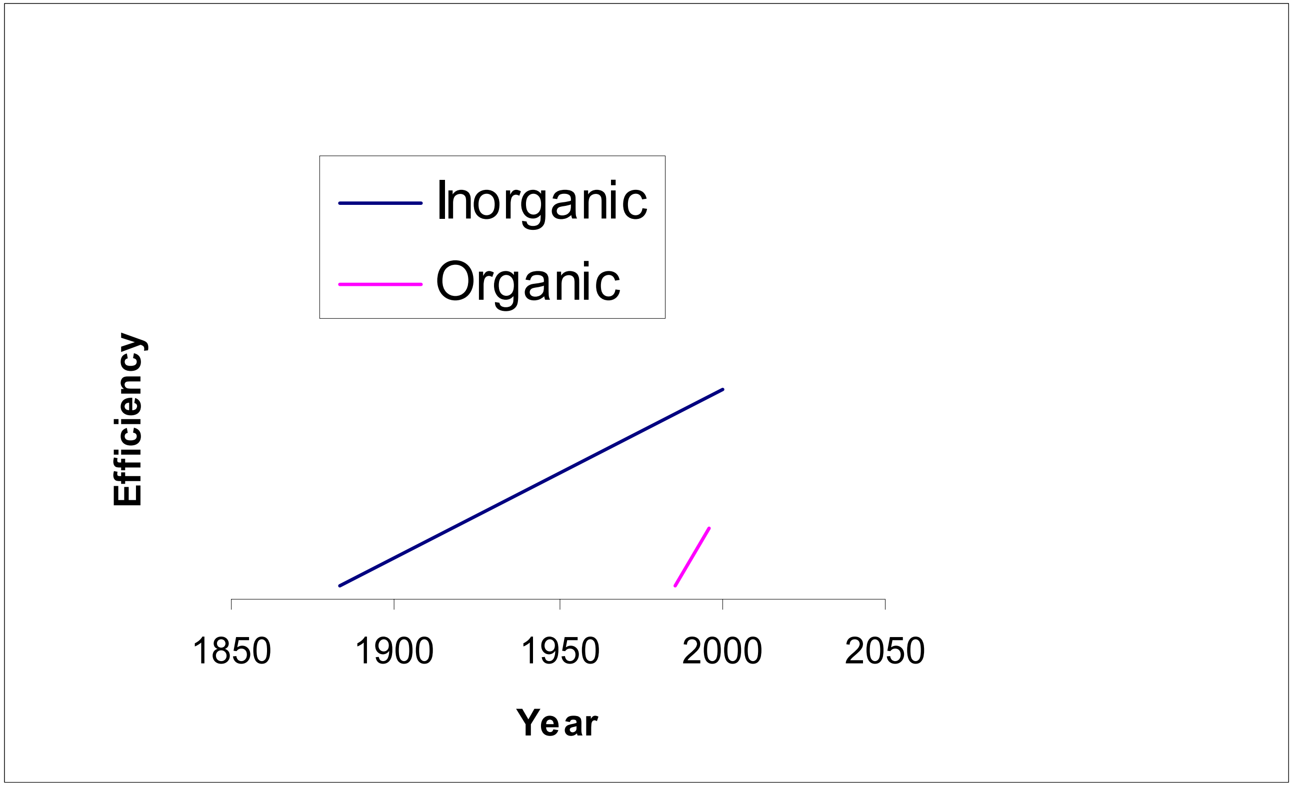
Free, Unlimited

Sun Light → **Organic Solar Cells** → **Electric Energy**

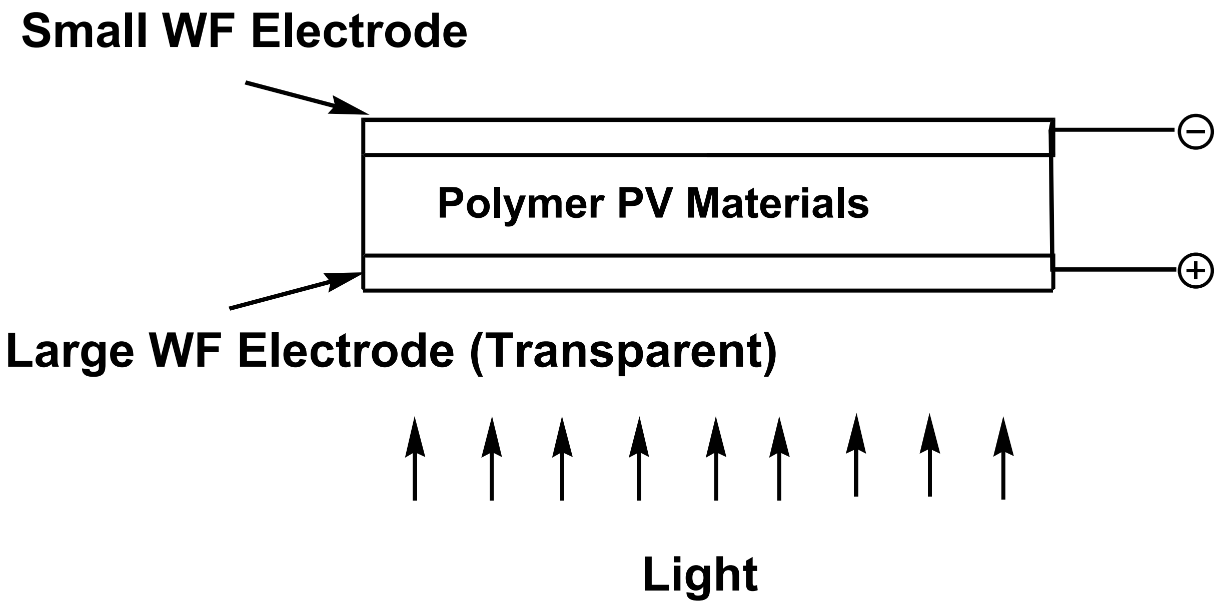
Photovoltaic Industry Growth (>30% world wide)



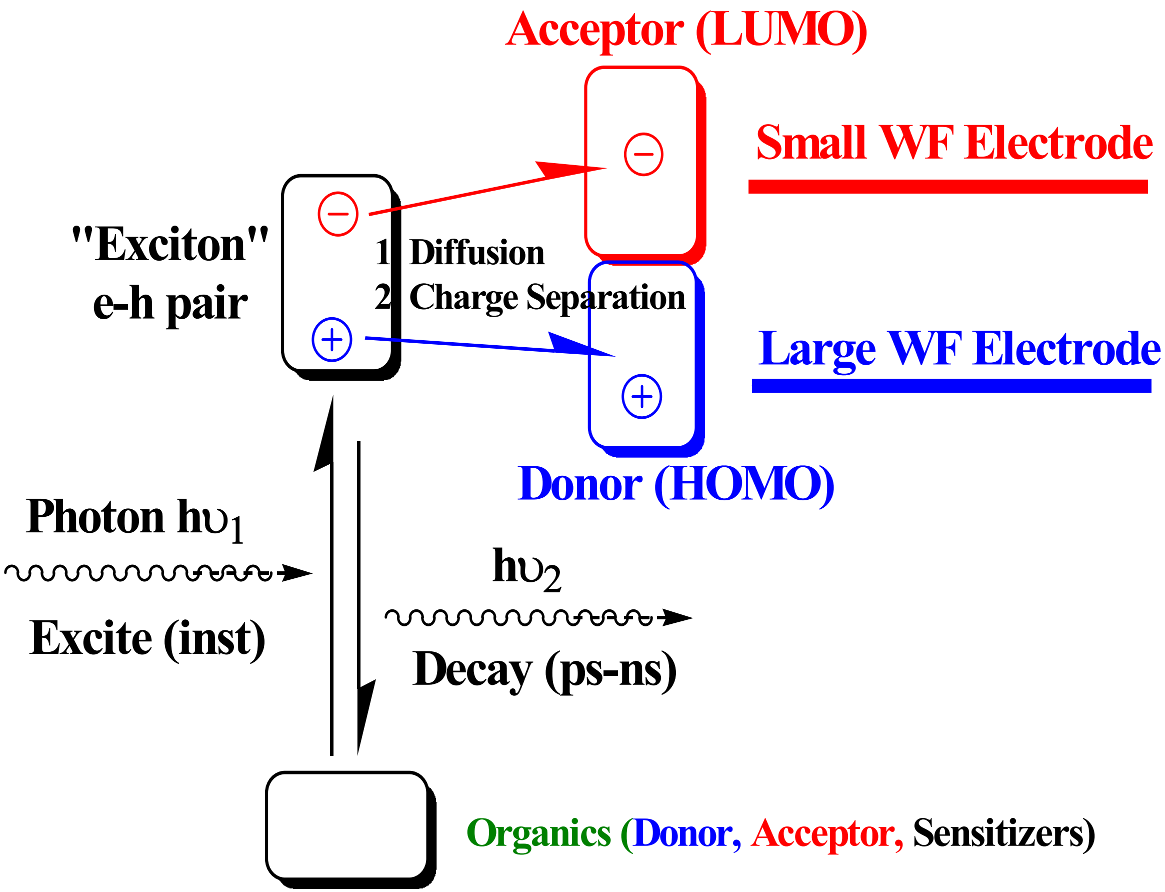
PV Efficiencies of Inorganic vs. Organic



A Polymer Photovoltaic Cell

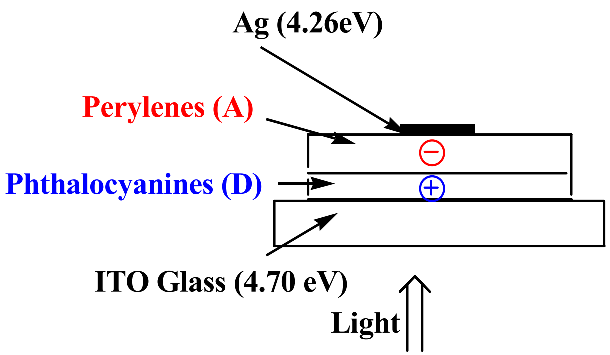


A Simplified Scheme of Photovoltaic Process in Organic Donor/Acceptor Binary Systems



First D/A Type Organic Solar Cell
'Tang Cell'

First Organic Solar Cell (D-A double layer)

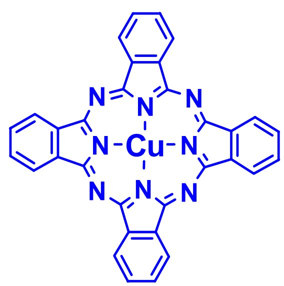


C. W. Tang

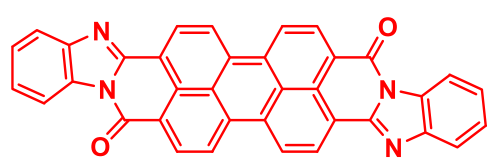
Eastman Kodak Co.

Appl. Phys. Lett., 48(2), 183(1986)

Efficiency 1%
0.75 Sun @ AM 2
Voc = 0.45 V
Isc = 2.3 mA/cm^2



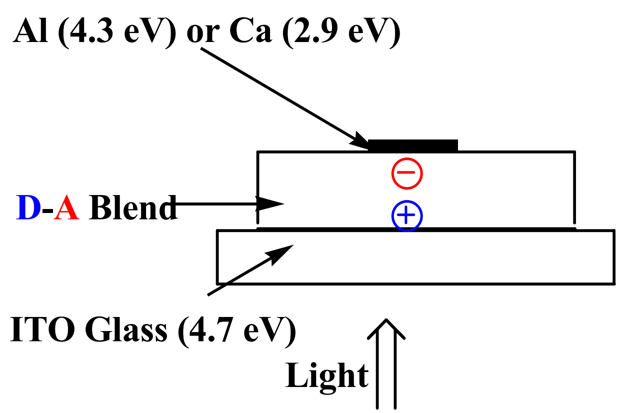
Phthalocyanines (Donor)



Perylenes (Acceptor)

C_{60}/MEH-PPV Blend Single Layer Solar Cell

"Bulk D-A Heterojunctions" Single Layer Organic Solar Cell 2

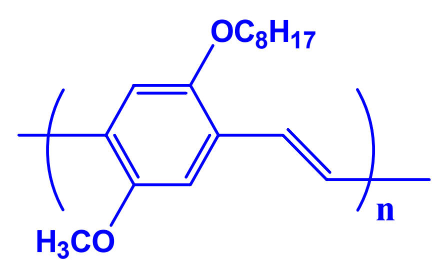


<u>N . Sariciftci & A. Heeger, et. al.</u>
<u>Science, 258, 1474 (1992)</u>

<u>G. Yu & A. Heeger, et. al.</u>
UC Santa Babara
<u>Science, 270, 1789 (1995)</u>

Efficiency 5.5% (D-A Blend, 430 nm)
Efficiency 0.04% (D-A Double Layer)

C_{60} Derivatives (Acceptor)



MEH-PPV (Donor)

Five Critical Steps in Organic Photovoltaic

1. **Photon Absorption (Band gaps, *e.g*., 1.3-2.0 eV on surface of the earth, 1.8-3.0 eV in space, Materials Engineering at <u>Energy Domain</u>).**
2. **Exciton Diffusion (D/A interface within 10-70 nm region, Materials Engineering at <u>Spatial Domain</u>).**
3. **Charge Separation (Orbital Offsets, Materials Engineering at <u>Energy Domains</u>).**
4. **Charge Transportation (Morphology, Materials Engineering at <u>Spatial Domain</u>)**
5. **Charge Collection at Electrodes (Engineering at <u>Energy Domain</u>)**

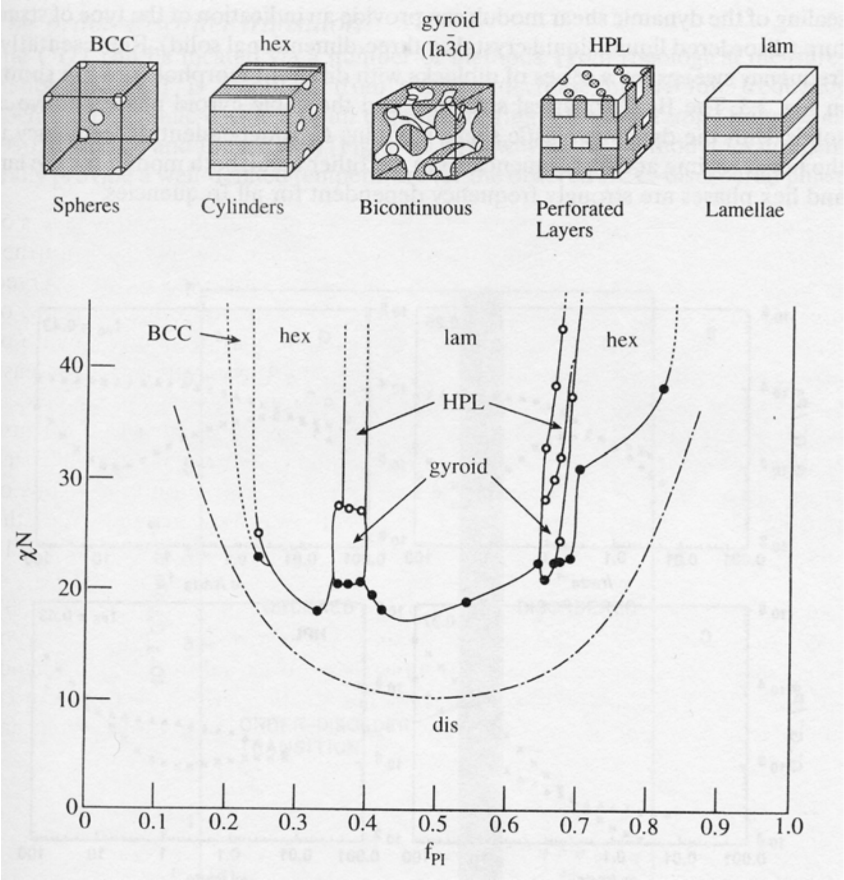
Three Key 'Losses' of Organic Photovoltaics

- **1. Photon Loss (Light Wavelength/Spectra vs. Band Gap)**
- **2. Exciton Loss (D/A Domain Size/Morphology/Energy Levels)**
- **3. Carrier Loss (Transport Pathway/Morphology/Molecular Packing/Collection at Electrodes)**

Optimizations at Spatial Domain

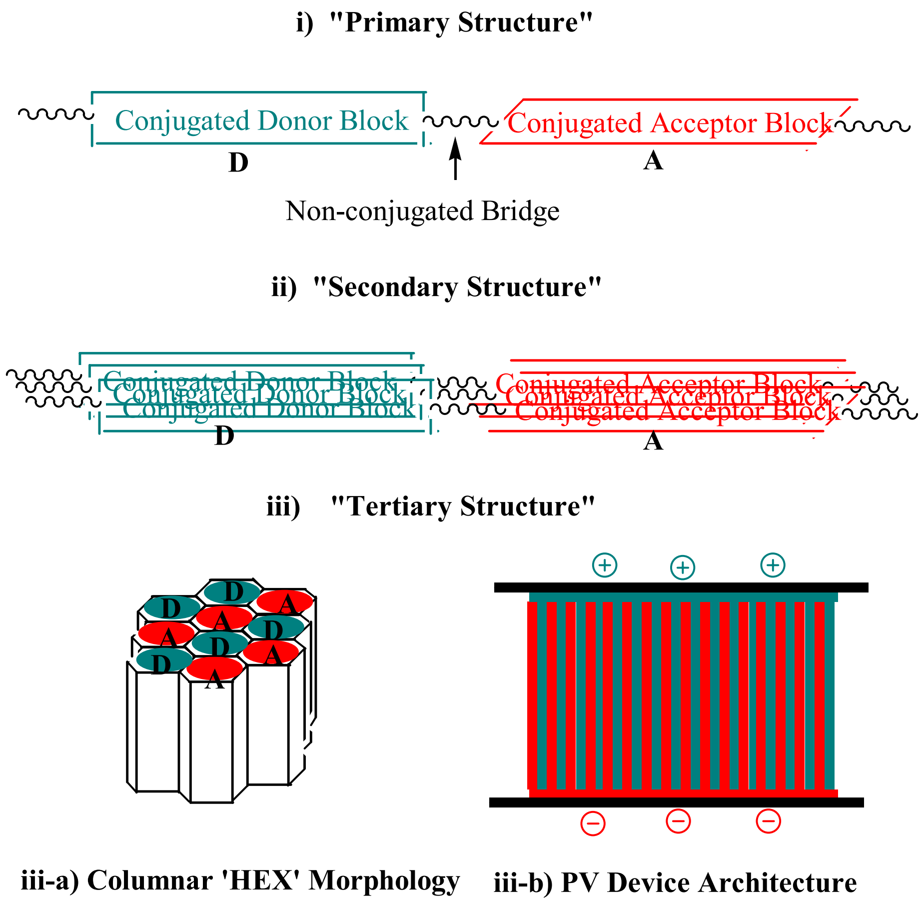
PS-PI Diblock Copolymer Phase Diagram

(Bates, F. S., *et al.*, *Macromolecules*, **1995**, *28*, 8796)

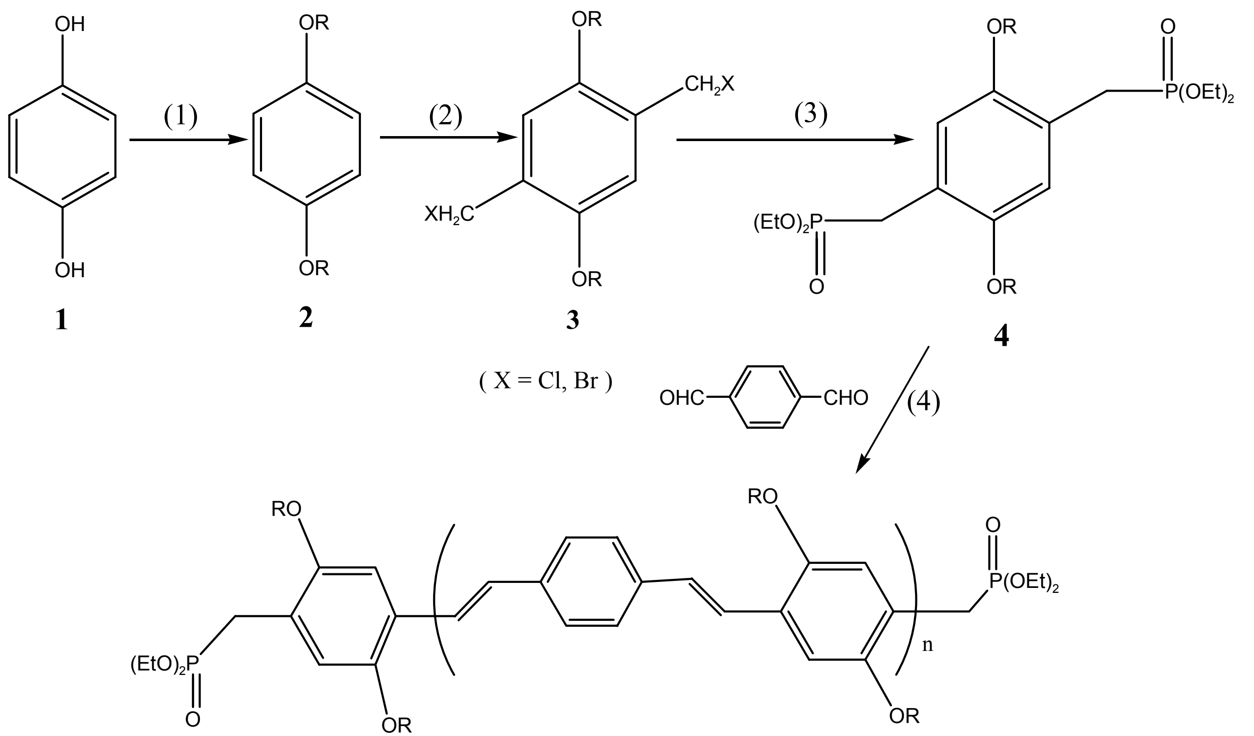


A 'Tertiary' Nano Structured Block Copolymer Approach

(Sun, S., *Sol. Energy Mater. Sol. Cells*, **2003**, *79(2)*, 257-264)

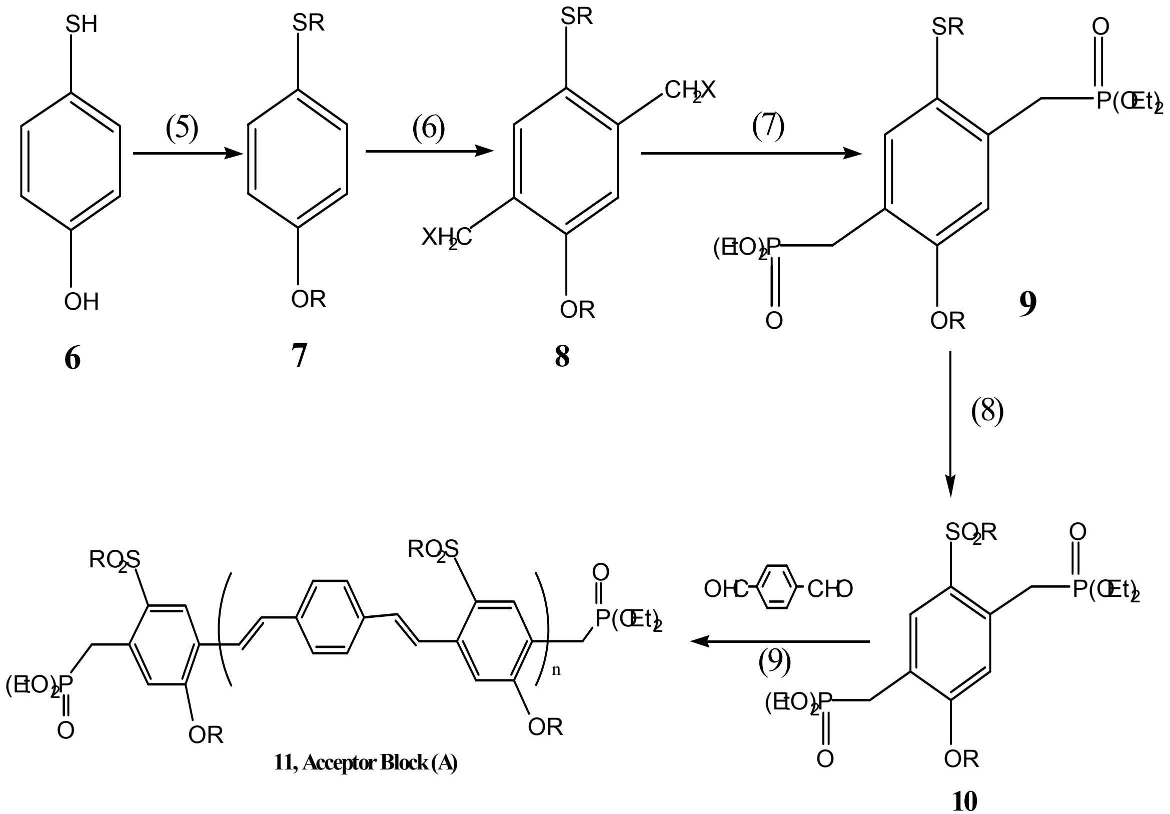


Donor Block Synthesis

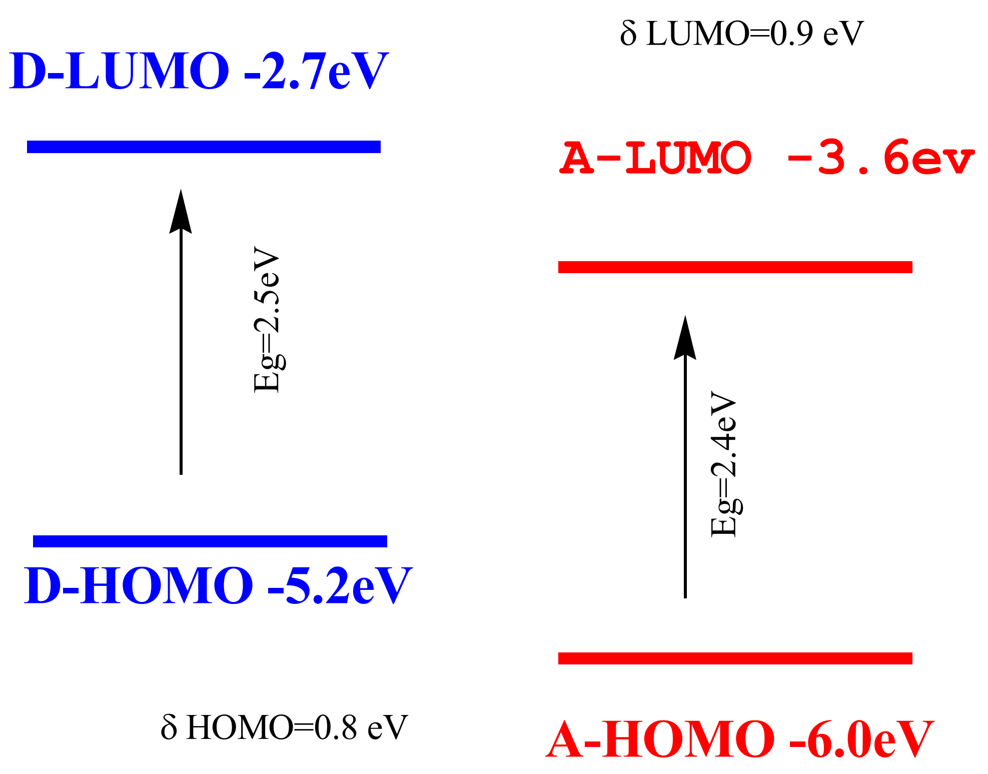


5, Donor Block (D)

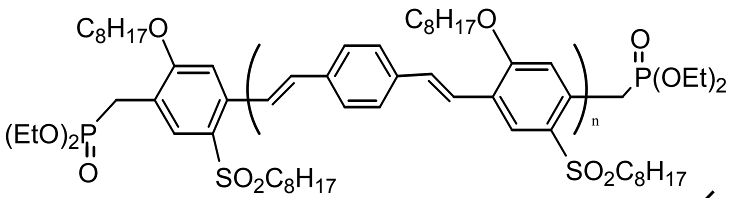
Acceptor Block Synthesis



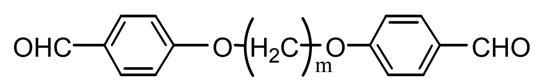
HOMO-LUMO Levels of RO-PPV and SF-PPV-I



Synthesis of Block Copolymers



+ 2



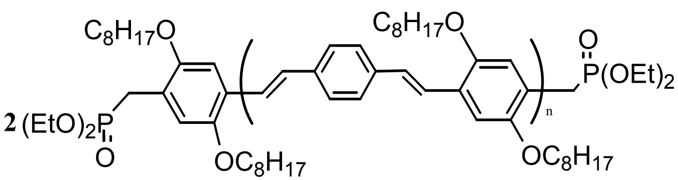
15, Bridge Block (B)

11, Acceptor Block (A)

-B-A-B-

16

+ 2



5, Donor Block (D)

-D-B-A-B-D- **or** **-A-B-D-B-A-**

17 **19**

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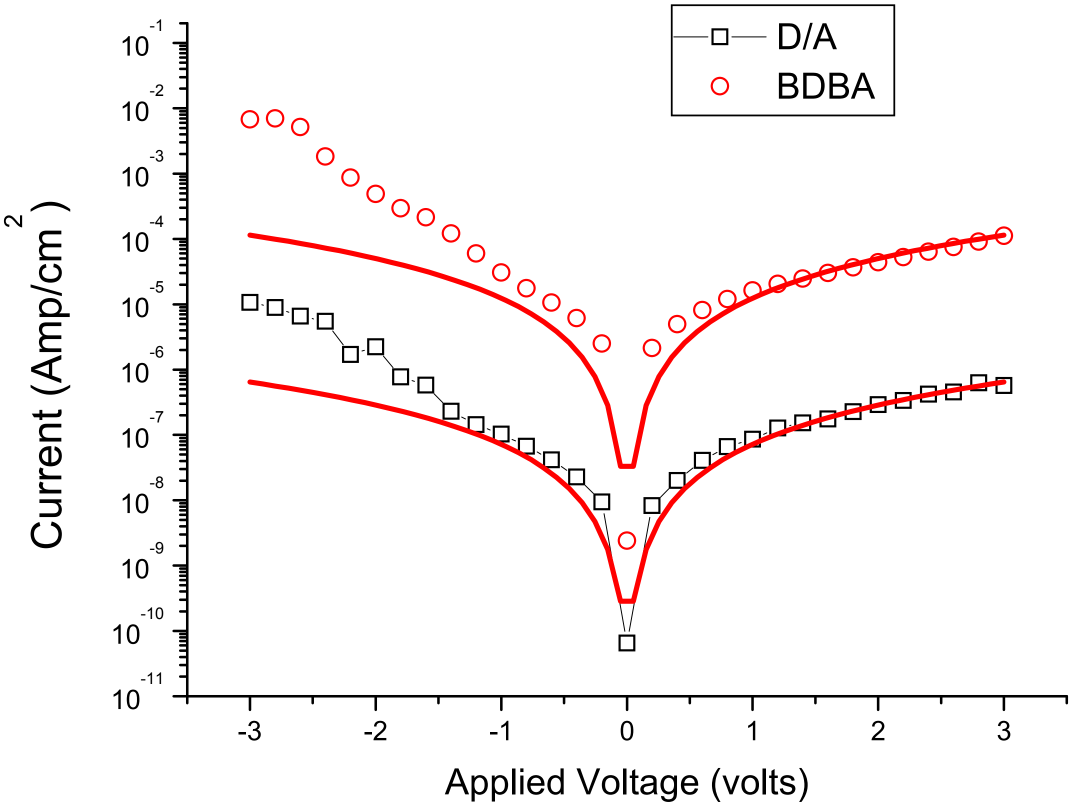
Synthetic Scheme of a B-D-B-A Block Copolymer

a) $A + 2B \rightarrow B\text{-}A\text{-}B \xrightarrow{D} \text{-}(B\text{-}A\text{-}B\text{-}D)\text{-}$

b) $D + 2B \rightarrow B\text{-}D\text{-}B \xrightarrow{A} \text{-}(B\text{-}D\text{-}B\text{-}A)\text{-}$

Current Density of D/A vs. BDBA in Dark



Optimizations at Energy Domain

Scheme of Photo Induced Electron Transfer Processes of a D/A Pair
I: Frontier Orbital Level Diagram

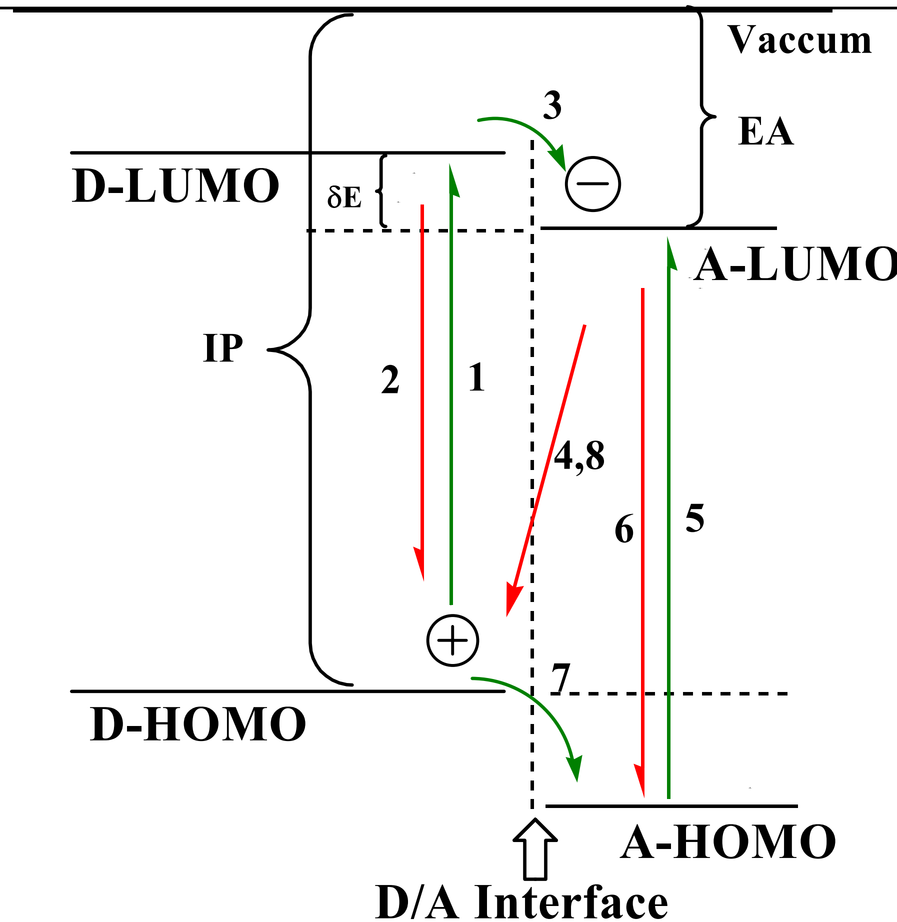
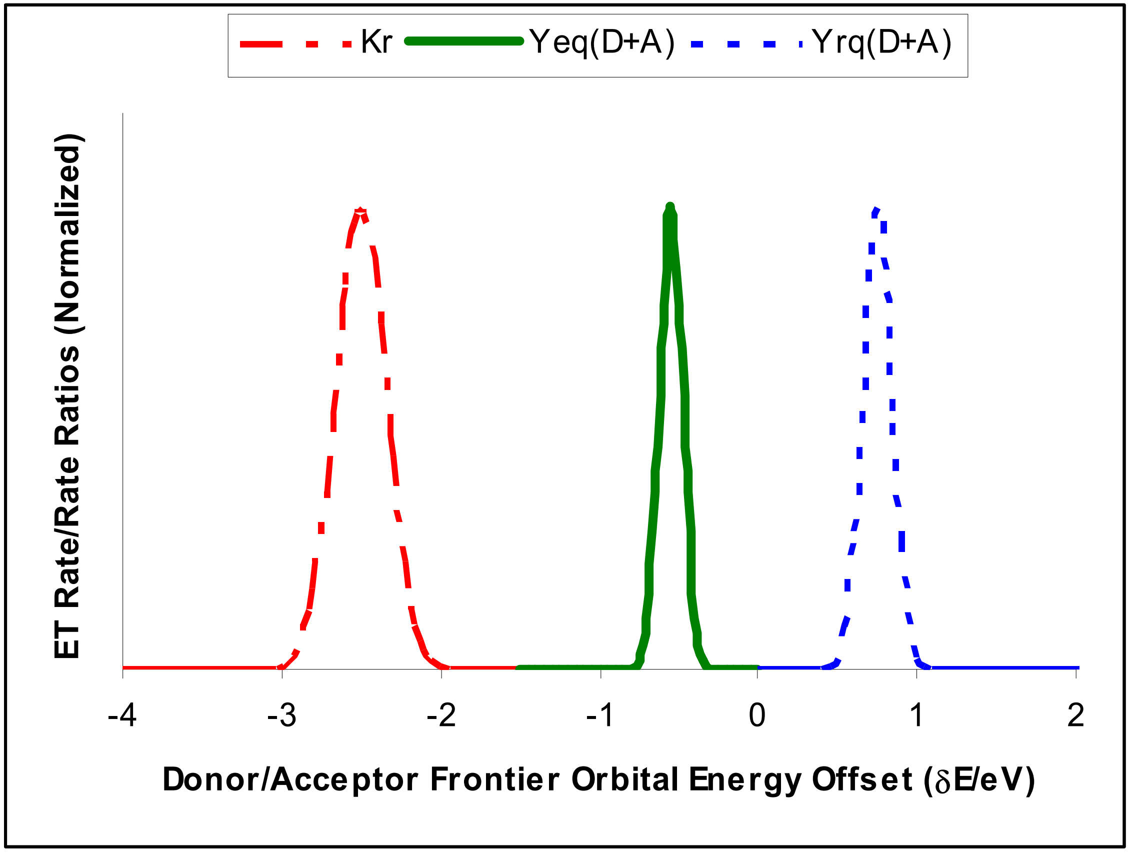


Photo Induced Electron Transfer Rates/Rate Ratios vs. LUMO offsets

(Sun, S., *Sol. Energy Mater. Sol. Cells*, **2004**, published online 6/20/2004)



Summary

- **1.** Current low efficiency of organic solar cells can be attributed mainly to the 'photon loss', the 'exciton loss', and the 'carrier loss'. High efficiency organic solar cells should be optimized at both space and energy domains.
- **2.** At spatial domain, for instance, a conjugated –DBAB- type primary structured block copolymer PV device has been designed, where D is a π orbital conjugated donor block, A is a π orbital conjugated acceptor block, and B is a non-conjugated and flexible bridge unit. The secondary structure refers to the π conjugated chains closely stacked and self-assembled ordered morphology. The tertiary structure is a columnar or 'HEX' morphology sandwiched between a donor and an acceptor layer. Preliminary experimental data demonstrated the synthesized –BDBA- block copolymer exhibits much better performances on morphology, photoluminescence quenching, and photoelectric responses in comparison to the blends under identical conditions.
- **3.** At energy domain, materials should be engineered to achieve an optimum donor/acceptor frontier orbital levels and offsets where the exciton quenching and recombination quenching are most efficient, and charge recombination is minimum.

Preparing Chemical Reactions

Removing Solvent

Operating Dry Glove Box

FT-IR/Raman Analysis

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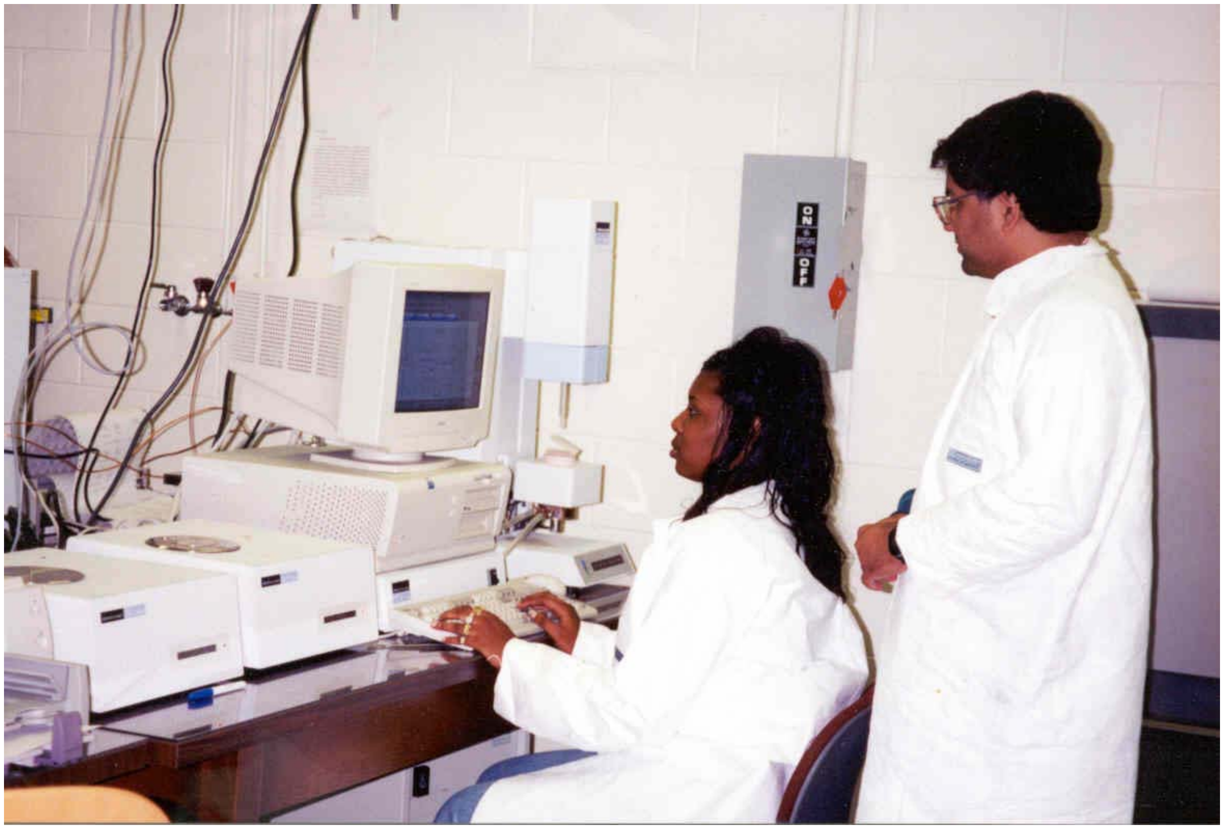
Measuring Polymer Molecular Size

Materials Thermal Analysis



Selected Publications Relevant to ‘OPV’ Project

1. Sun, S. and Sariciftci, N. eds., **“Organic Photovoltaics: Mechanisms, Materials and Devices”,** CRC/Dekker, **2004**, in press.
2. Sun, S., “**Optimal energy offsets for organic solar cells containing a donor/acceptor pair**”, *Sol. Energy. Mater. Sol. Cells*, published online **June 20**, **2004**.
3. Sun, S., **“Optimum energy levels and offsets for organic donor/acceptor binary photovoltaic materials and solar cells ”,** *Mater. Sci. & Eng., B.,* **2004***,* in press.
4. Sun, S., “**Design and Development of Conjugated Block Copolymers for Use in Photovoltaic Devices**”, in *Organic Photovoltaics IV*, SPIE, **2004**, vol. 5215, pp195-205.
5. Sun, S., “**Design of a Block Copolymer Solar Cell**”, *Sol. Energy Mater. Sol. Cel.*, **2003**, *79(2),* 257-264.
6. Sun, S.; Fan, Z.; Wang, Y.; Haliburton, J.; Taft, C.; Seo, K.; Bonner, C., “**Conjugated Block Copolymers for Opto-Electronic Functions**”, *Syn. Met*., **2003**, *137(1-3)*, 883-884.
7. Sun, S.; Fan, Z.; Wang, Y.; Taft, C.; Haliburton, J.; Maaref, S.; “**Synthesis and Characterization of a Novel –D-B-A-B-Block Copolymer System for Light Harvesting Applications**”, *SPIE*, **2003**, vol. 4801, pp114-124.
8. Sun, S., “**Block Copolymers for Photovoltaics**”, *Poly. Mater. Sci. Eng.*, **2003**, *88*, 158.
9. Maaref, S and Sun, S., “**New Terminal Functionalized Polythiophenes with Size Control**”, *Poly. Mater. Sci. Eng.*, **2003**, *88*, 510.
10. Thomas, S. and Sun, S., “**Synthesis and Characterization of a New Polythiophene with Fluorinated Substituents**”, *Poly. Prepr.*, **2003**, *441(1)*, 891.
11. Sun, S., “**Photovoltaic Devices Based on a Novel Conjugated Block Copolymer**”, *patent published* **May 27, 2004**.
12. Ma, J.; Song, H.; Frisch, H. L; Maaref, S.; Sun, S., “**Electrically Conductive Semi-IPNs Based on Polyaniline and Crosslinked Polyvinylacetate**”, *J. Appl. Poly. Sci.*, **2002**, *85(11)*, 2287-2293.
13. Fan, Z.; Wang, Y.; Taft, C.; Haliburton, J.; Maaref, S. and Sun, S., “**Synthesis and Characterization of a novel block copolymer containing donor and acceptor blocks**”, *Poly. Mater. Sci. Egn.,* **2002,** *86,* 47.
14. Sun, S.; Fan, Z.; Wang, Y.; Taft, C.; Haliburton, J.; Maaref, S.; “**Design and Synthesis of Novel Block Copolymers for Efficient Opto-Electronic Applications**”, *SPIE*, **2002**, vol. 4465, pp 121-128.